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Jeong et al.

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(54) **METHOD OF MANUFACTURING SEMICONDUCTOR DEVICE**

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H01L 29/66 (2006.01)
H01L 21/324 (2006.01)
- (52) **U.S. Cl.**
CPC **H01L 21/02236** (2013.01); **H01L 21/02318** (2013.01); **H01L 21/324** (2013.01)
- (58) **Field of Classification Search**
None
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(57) **ABSTRACT**

The inventive concepts provide methods of manufacturing a semiconductor device including a thermal treatment process. The method may include providing a substrate including a channel region of a transistor, forming an initial oxide layer on the channel region, and performing a thermal treatment process at least once before or after forming the initial oxide layer.

15 Claims, 14 Drawing Sheets

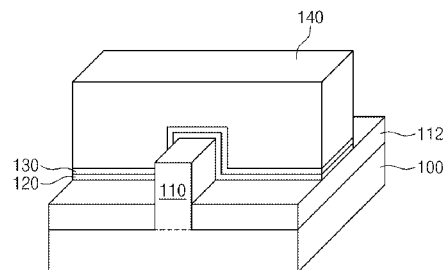
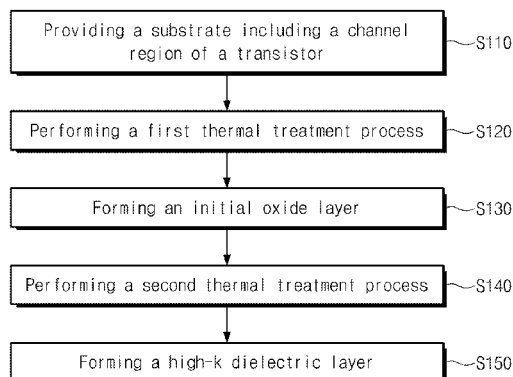


FIG. 1

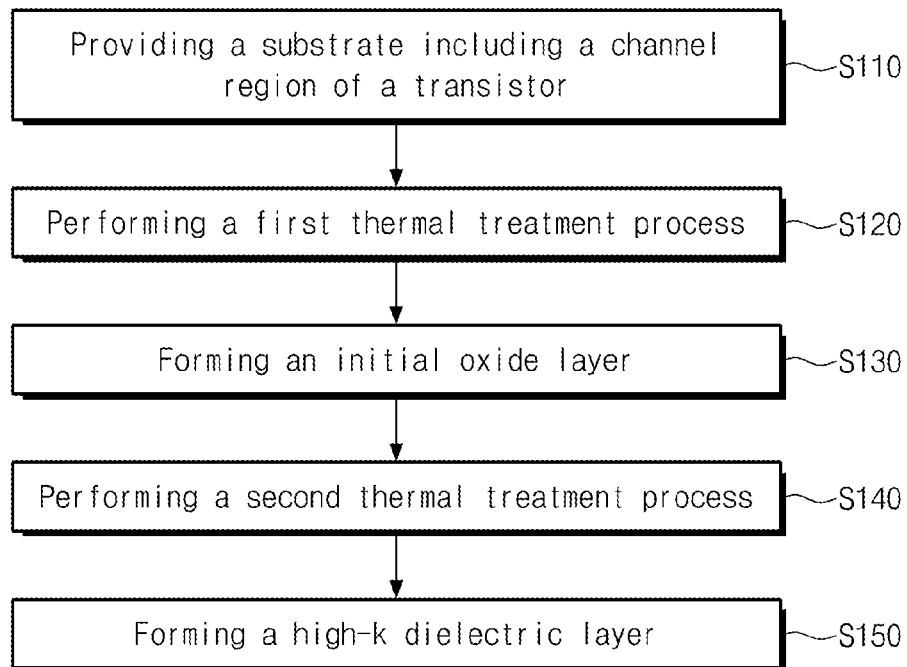


FIG. 2

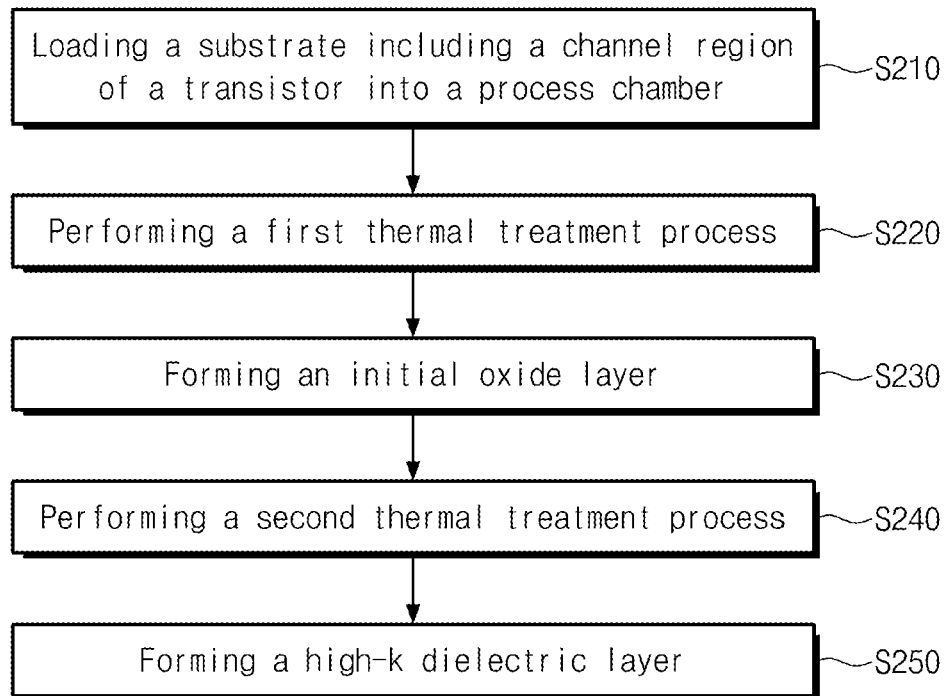


FIG. 3

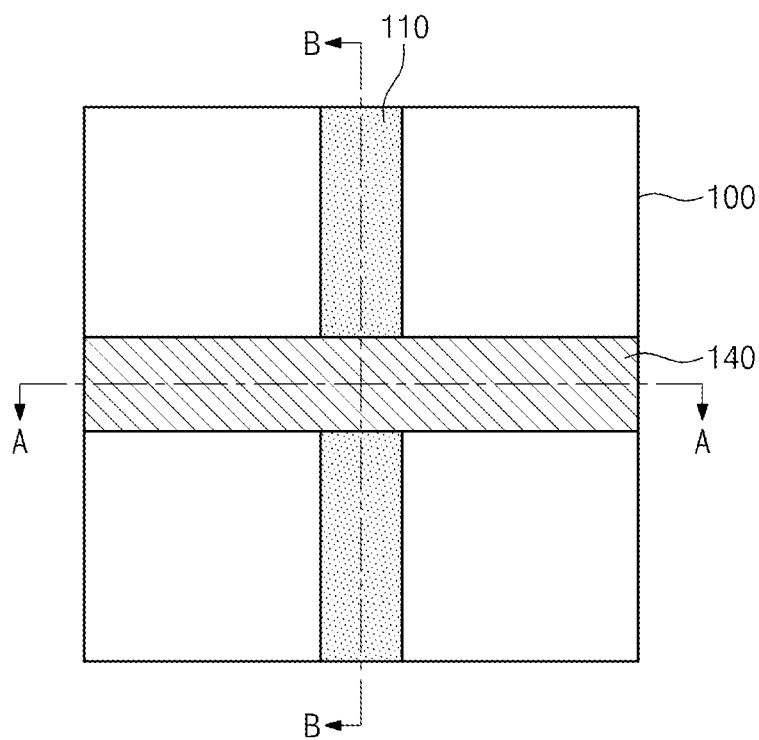


FIG. 4A

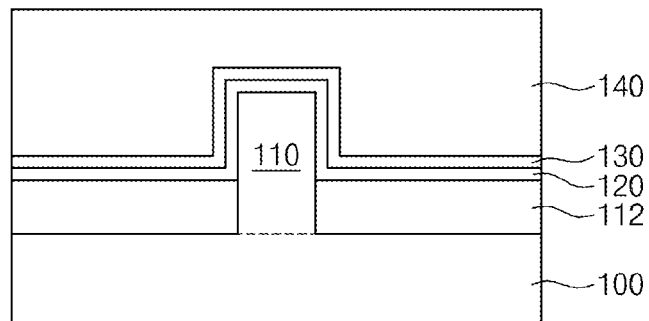


FIG. 4B

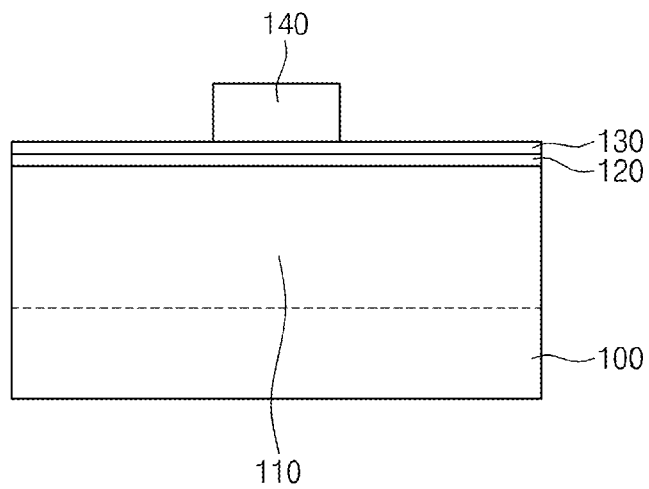


FIG. 5A

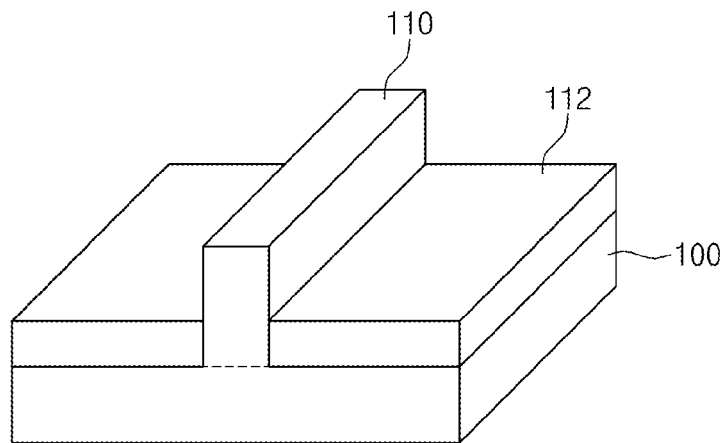


FIG. 5B

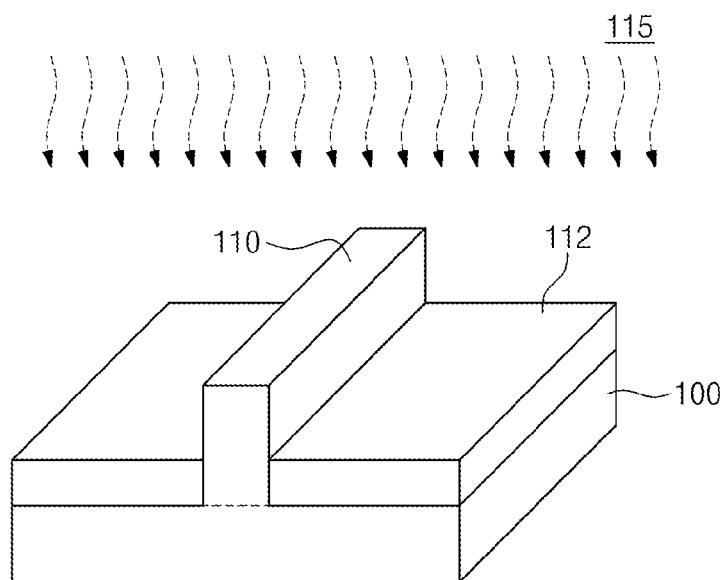


FIG. 5C

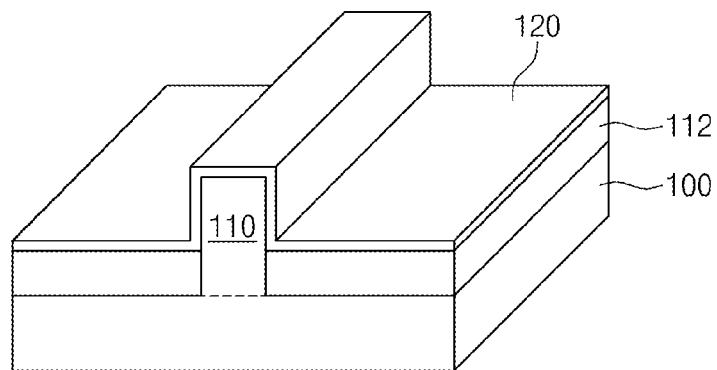


FIG. 5D

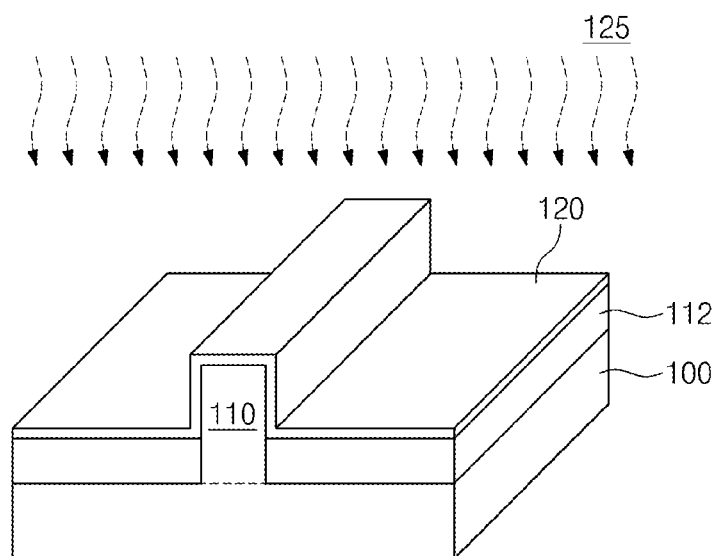


FIG. 5E

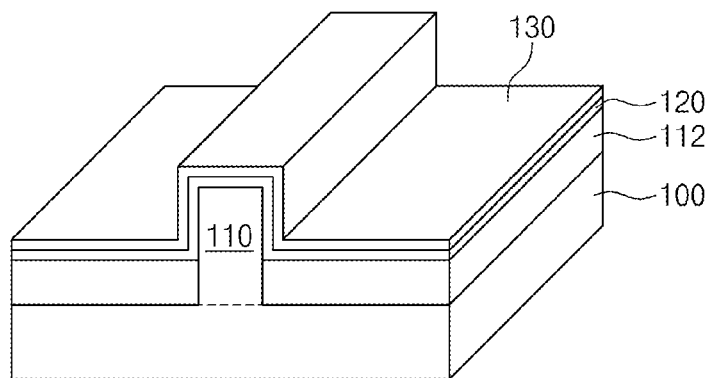


FIG. 5F

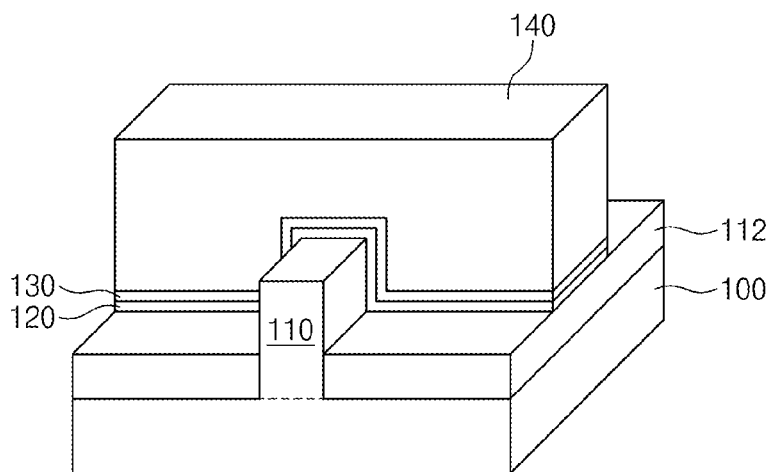


FIG. 6A

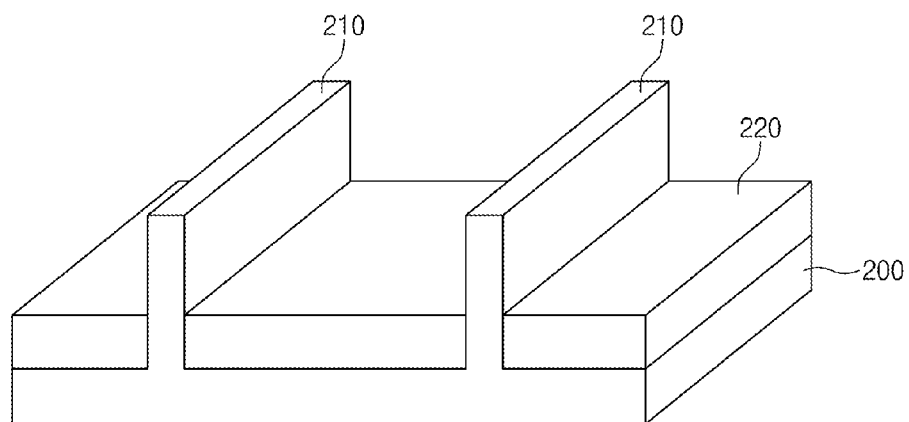


FIG. 6B

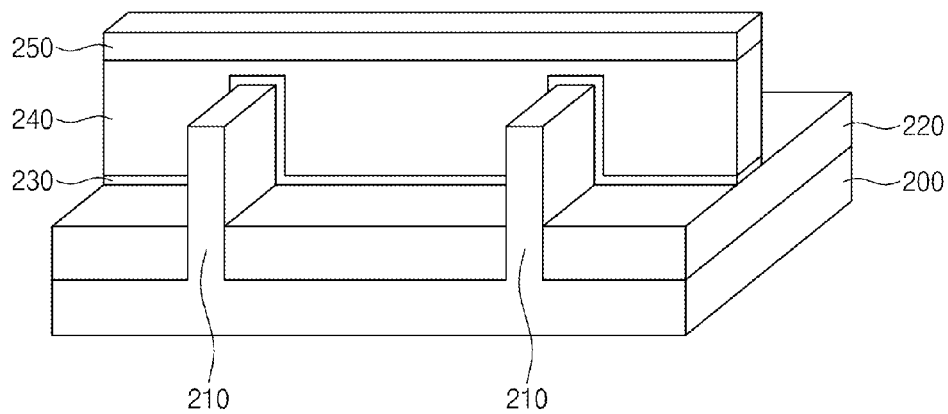


FIG. 6C

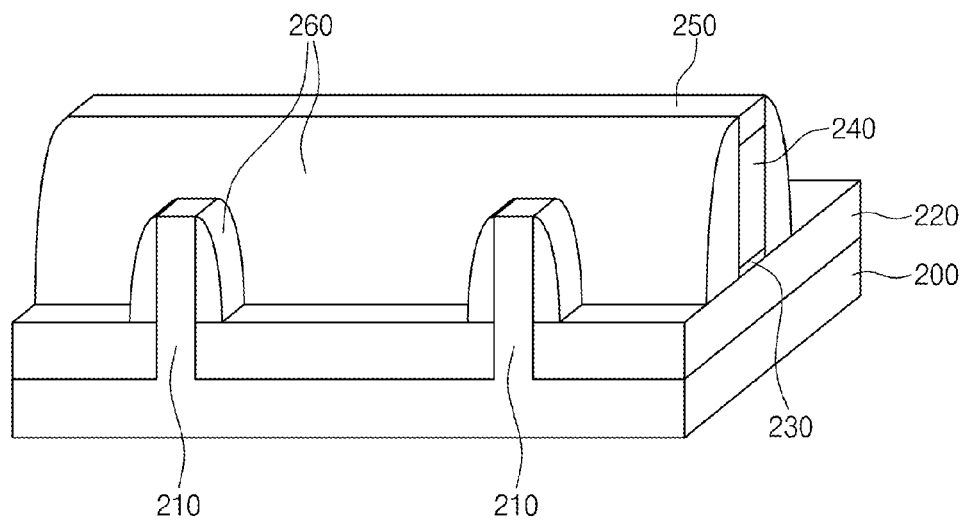
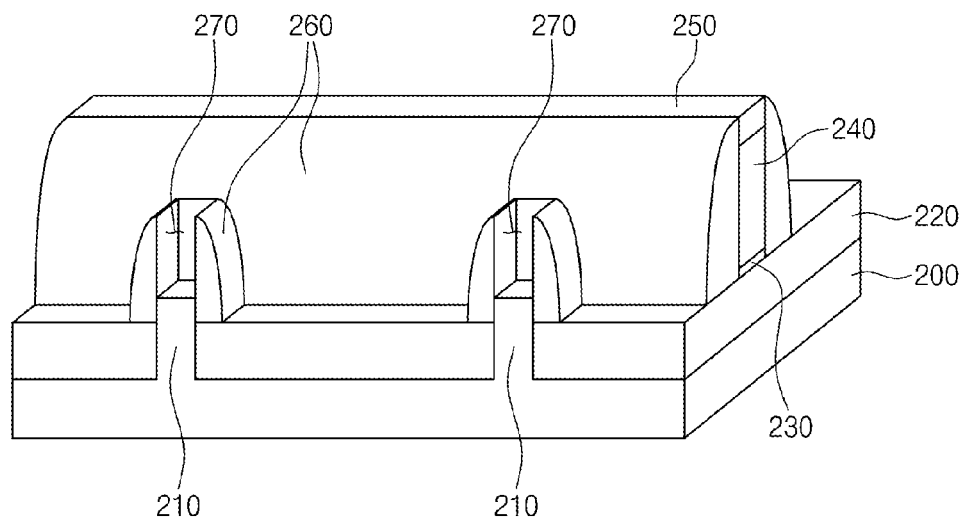


FIG. 6D



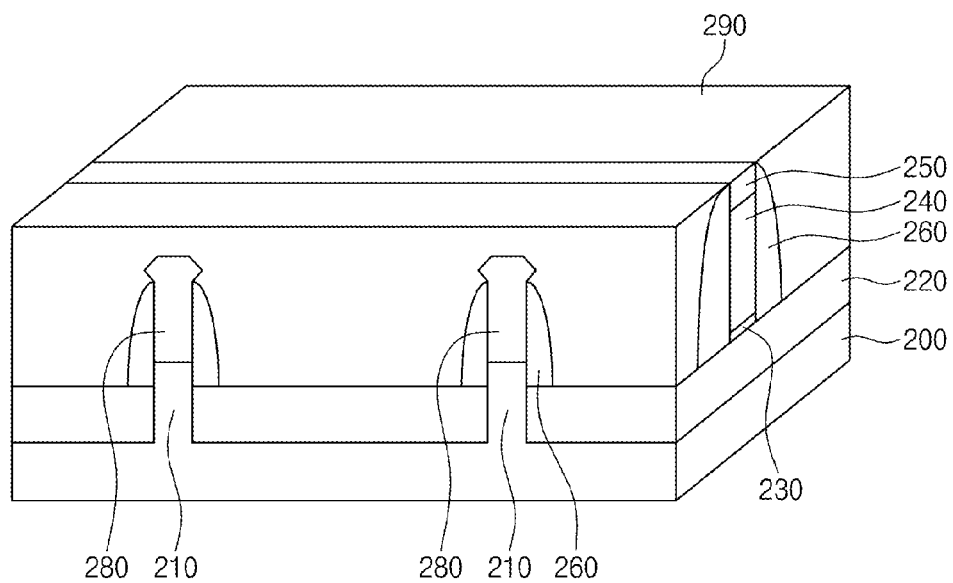


FIG. 6G

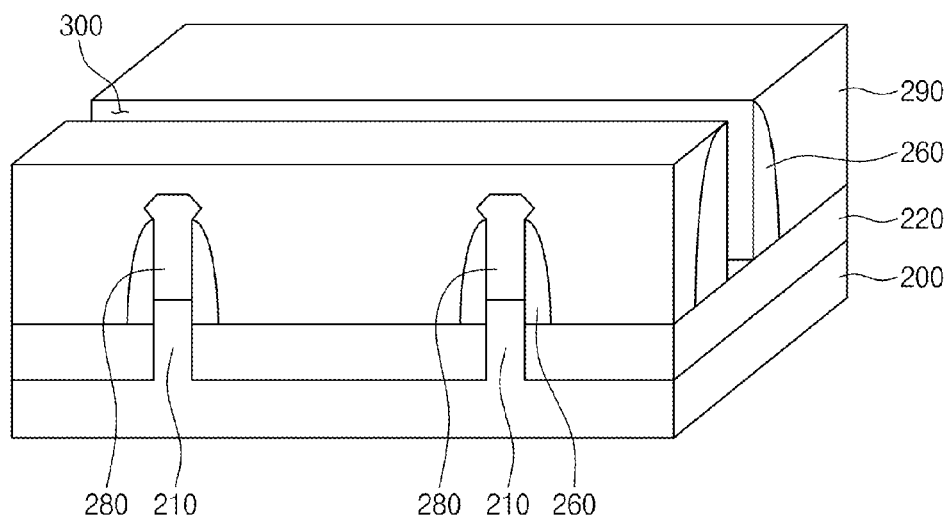


FIG. 6H

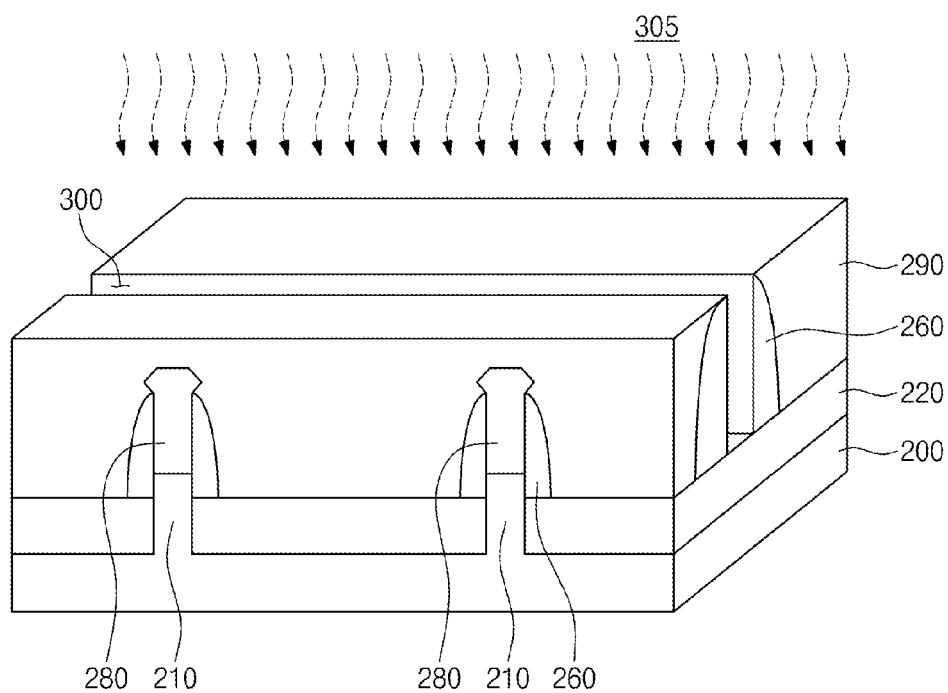


FIG. 6I

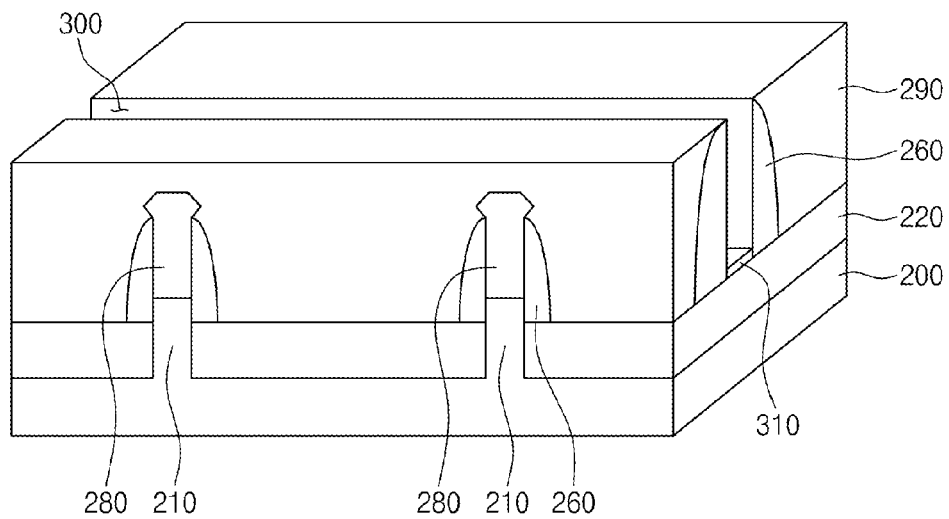


FIG. 6J

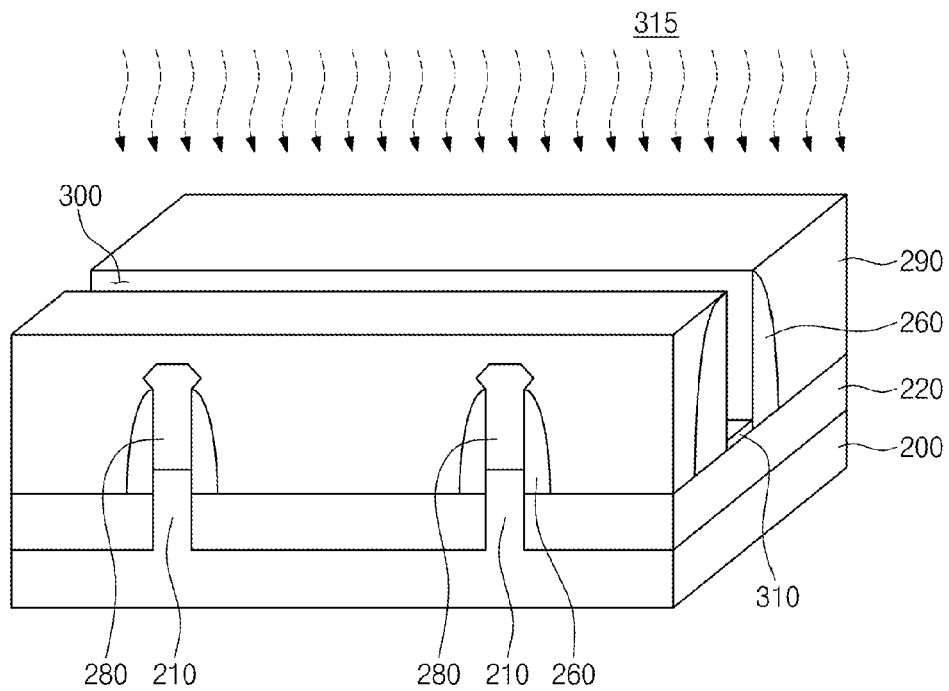


FIG. 6K

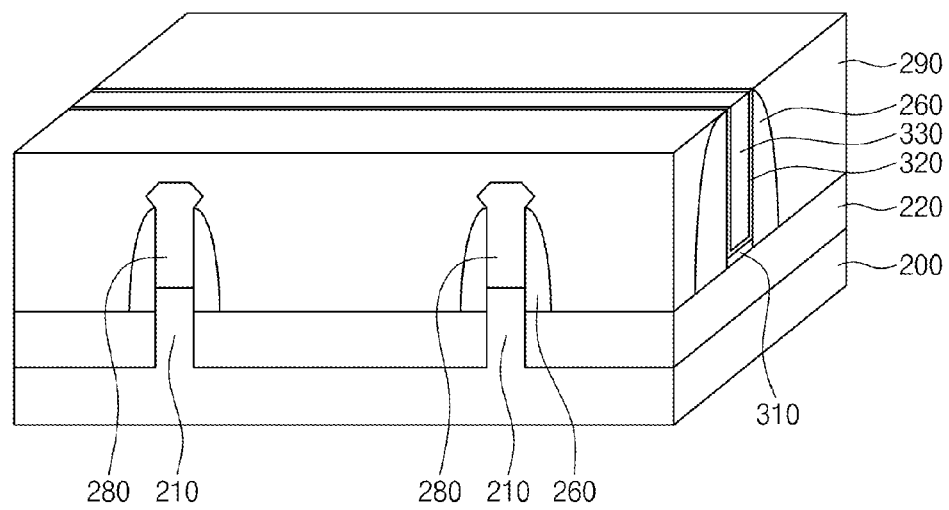


FIG. 7

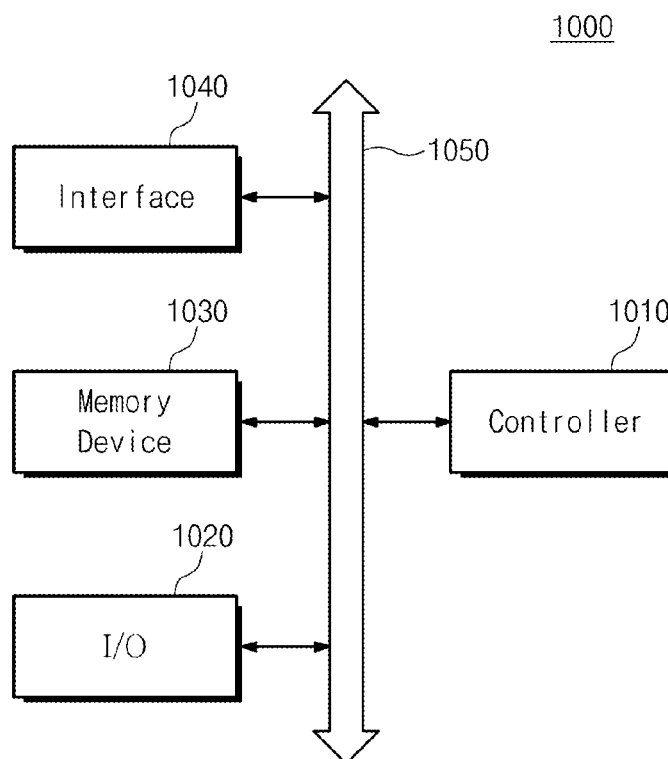
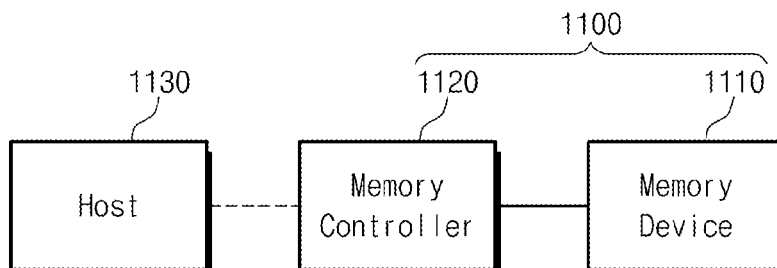


FIG. 8



METHOD OF MANUFACTURING SEMICONDUCTOR DEVICE

TECHNICAL FIELD

The inventive concepts relate to methods of manufacturing a semiconductor device and, more particularly, to methods of manufacturing a semiconductor device capable of improving reliability of a gate dielectric layer of a transistor.

DESCRIPTION OF RELATED ART

As semiconductor devices have been highly integrated and design rules have been reduced, thicknesses of gate dielectric layers have been reduced to improve current driving ability of transistors. Thus, a time dependent dielectric breakdown (TDDB) characteristic corresponding to one of reliability-evaluation items on the gate dielectric layer may directly affect characteristics and/or reliability of an entire semiconductor device, as well as characteristics of a transistor.

SUMMARY

Embodiments of the inventive concepts may provide methods of manufacturing a semiconductor device capable of improving reliability of a gate dielectric layer of a transistor.

In some example embodiments, a method of manufacturing a semiconductor device may include: providing a substrate including a channel region of a transistor; forming an initial oxide layer on the channel region; and performing a thermal treatment process at least once before or after forming the initial oxide layer.

In some example embodiments, the channel region may include germanium (Ge).

In some example embodiments, the method may further include: forming a high-k dielectric layer on the initial oxide layer.

In some example embodiments, the thermal treatment process may be performed using at least one of oxygen, nitrogen, argon, or ultraviolet (UV) radiation in-situ in a process chamber in which the initial oxide layer is formed.

In some example embodiments, the thermal treatment process may be performed at a temperature in a range of 550° C. to 750° C.

In some example embodiments, the thermal treatment process may be performed using at least one of oxygen, nitrogen, or argon gas at a flow rate in a range of 100 sccm to 5000 sccm.

In some example embodiments, the thermal treatment process may be performed at a pressure in a range of 0.1 Torr to 10 Torr.

In some example embodiments, the thermal treatment process may be performed using the ultraviolet (UV) radiation at a pressure in a range of 0 Torr to 0.01 Torr.

In some example embodiments, the thermal treatment process may be performed for a time in a range of 30 seconds to 200 seconds.

In some example embodiments, a method of manufacturing a semiconductor device may include: providing a substrate having a channel region including silicon-germanium (SiGe); forming an initial oxide layer on the substrate; and performing a first thermal treatment process using at least one of oxygen, nitrogen, argon, or ultraviolet (UV) radiation in-situ before forming the initial oxide layer.

In some example embodiments, the method may further include: performing a second thermal treatment process using at least one of oxygen, nitrogen, argon, or ultraviolet (UV) radiation in-situ after forming the initial oxide layer.

In some example embodiments, the second thermal treatment process may be performed by substantially the same method as the first thermal treatment process.

In some example embodiments, each of the first and second thermal treatment processes may be performed at a temperature in a range of 550° C. to 750° C.

In some example embodiments, each of the first and second thermal treatment processes may be performed at least one of using oxygen, nitrogen, or argon gas at a flow rate in a range of 100 sccm to 5000 sccm and at a pressure in a range of 0.1 Torr to 10 Torr.

In some example embodiments, each of the first and second thermal treatment processes may be performed using the ultraviolet (UV) radiation at a pressure in a range of 0 Torr to 0.01 Torr.

In some example embodiments, the method may further include: forming a high-k dielectric layer on the initial oxide layer.

In some example embodiments, a method of manufacturing a semiconductor device may include: loading a substrate having a channel region of a transistor into a process chamber, the channel region including silicon-germanium (SiGe); performing a first thermal treatment process using at least one of oxygen, nitrogen, argon, or ultraviolet (UV) radiation on the channel region; forming an initial oxide layer on the channel region treated by the first thermal treatment process in-situ in the process chamber; and performing a second thermal treatment process using at least one of oxygen, nitrogen, argon, or ultraviolet (UV) radiation on the initial oxide layer.

In some example embodiments, the second thermal treatment process may be performed in-situ in the process chamber.

In some example embodiments, the method may further include: forming a high-k dielectric layer on the initial oxide layer after performing the second thermal treatment process.

BRIEF DESCRIPTION OF THE DRAWINGS

The inventive concepts will become more apparent in view of the attached drawings and accompanying detailed description.

FIG. 1 is a process flow chart illustrating a method of manufacturing a semiconductor device according to some example embodiments of the inventive concepts;

FIG. 2 is a process flow chart illustrating a method of manufacturing a semiconductor device according to other example embodiments of the inventive concepts;

FIG. 3 is a plan view illustrating a semiconductor device according to some example embodiments of the inventive concepts;

FIG. 4A is a cross-sectional view taken along a line A-A of FIG. 3;

FIG. 4B is a cross-sectional view taken along a line B-B of FIG. 3;

FIGS. 5A to 5F are perspective views illustrating a method of manufacturing a semiconductor device according to some example embodiments of the inventive concepts;

FIGS. 6A to 6K are perspective views illustrating a method of manufacturing a semiconductor device according to other example embodiments of the inventive concepts;

FIG. 7 is a schematic block diagram illustrating a system including a semiconductor device according to example embodiments of the inventive concepts; and

FIG. 8 is a schematic block diagram illustrating a memory card including a semiconductor device according to example embodiments of the inventive concepts.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

The inventive concepts will now be described more fully hereinafter with reference to the accompanying drawings, in which example embodiments of the inventive concepts are shown. The advantages and features of the inventive concepts and methods of achieving them will be apparent from the following example embodiments that will be described in more detail with reference to the accompanying drawings. It should be noted, however, that the inventive concepts are not limited to the following example embodiments, and may be implemented in various forms. Accordingly, the example embodiments are provided only to disclose the inventive concepts and let those skilled in the art know the category of the inventive concepts. In the drawings, example embodiments of the inventive concepts are not limited to the specific examples provided herein and are exaggerated for clarity.

It will be understood that when an element is referred to as being “connected” or “coupled” to another element, it can be directly connected or coupled to the other element or intervening elements may be present. In contrast, when an element is referred to as being “directly connected” or “directly coupled” to another element, there are no intervening elements present. Like numbers indicate like elements throughout. As used herein the term “and/or” includes any and all combinations of one or more of the associated listed items. Other words used to describe the relationship between elements or layers should be interpreted in a like fashion (e.g., “between” versus “directly between,” “adjacent” versus “directly adjacent,” “on” versus “directly on”).

The terminology used herein is for the purpose of describing particular example embodiments only and is not intended to limit the invention. As used herein, the singular terms “a,” “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

Similarly, it will be understood that when an element such as a layer, region or substrate is referred to as being “on” another element, it can be directly on the other element or intervening elements may be present. In contrast, the term “directly” means that there are no intervening elements. It will be further understood that the terms “comprises,” “comprising,” “includes” and/or “including,” when used herein, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

Additionally, the embodiment in the detailed description will be described with sectional views as ideal example views of the inventive concepts. Accordingly, shapes of the example views may be modified according to manufacturing techniques and/or allowable errors. Therefore, the example embodiments of the inventive concepts are not limited to the specific shape illustrated in the example views, but may include other shapes that may be created according to manufacturing processes. Areas exemplified in the drawings have general properties, and are used to illustrate specific shapes of elements. Thus, this should not be construed as limited to the scope of the inventive concepts.

It will be also understood that although the terms first, second, third etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another element. Thus, a first element in some example

embodiments could be termed a second element in other example embodiments without departing from the teachings of the present invention. Example embodiments of aspects of the present inventive concepts explained and illustrated herein include their complementary counterparts. The same reference numerals or the same reference designators denote the same elements throughout the specification.

Moreover, example embodiments are described herein with reference to cross-sectional illustrations and/or plane illustrations that are idealized example illustrations. Accordingly, variations from the shapes of the illustrations as a result, for example, of manufacturing techniques and/or tolerances, are to be expected. Thus, example embodiments should not be construed as limited to the shapes of regions illustrated herein but are to include deviations in shapes that result, for example, from manufacturing. For example, an etching region illustrated as a rectangle will, typically, have rounded or curved features. Thus, the regions illustrated in the figures are schematic in nature and their shapes are not intended to illustrate the actual shape of a region of a device and are not intended to limit the scope of example embodiments.

Devices and methods of forming devices according to various example embodiments described herein may be embodied in microelectronic devices such as integrated circuits, wherein a plurality of devices according to various example embodiments described herein are integrated in the same microelectronic device. Accordingly, the cross-sectional view(s) illustrated herein may be replicated in two different directions, which need not be orthogonal, in the microelectronic device. Thus, a plan view of the microelectronic device that embodies devices according to various example embodiments described herein may include a plurality of the devices in an array and/or in an example two-dimensional pattern that is based on the functionality of the microelectronic device.

The devices according to various example embodiments described herein may be interspersed among other devices depending on the functionality of the microelectronic device. Moreover, microelectronic devices according to various example embodiments described herein may be replicated in a third direction that may be orthogonal to the two different directions, to provide three-dimensional integrated circuits.

Accordingly, the cross-sectional view(s) illustrated herein provide support for a plurality of devices according to various example embodiments described herein that extend along two different directions in a plan view and/or in three different directions in a perspective view. For example, when a single active region is illustrated in a cross-sectional view of a device/structure, the device/structure may include a plurality of active regions and transistor structures (or memory cell structures, gate structures, etc., as appropriate to the case) thereon, as would be illustrated by a plan view of the device/structure.

Methods of manufacturing a semiconductor device according to example embodiments will be described with reference to FIGS. 1 and 2. FIG. 1 is a process flow chart illustrating a method of manufacturing a semiconductor device according to some example embodiments of the inventive concepts, and FIG. 2 is a process flow chart illustrating a method of manufacturing a semiconductor device according to other example embodiments of the inventive concepts.

Referring to FIG. 1, a method of manufacturing a semiconductor device according to some example embodiments may include providing a substrate including a channel region of a transistor (S110), performing a first thermal treatment process on the substrate (S120), forming an initial oxide layer on the substrate (S130), performing a second thermal treatment

process on the initial oxide layer (S140), and/or forming a high-k dielectric layer on the initial oxide layer (S150).

In some example embodiments, one of the first thermal treatment process and the second thermal treatment process may be omitted.

The substrate may be a silicon substrate such as a bulk silicon substrate or a silicon-on-insulator (SOI) substrate. The channel region of the transistor may include germanium (Ge). For example, the channel region of the transistor may be formed of silicon-germanium (SiGe).

The first thermal treatment process may be performed on the substrate using at least one of oxygen, nitrogen, argon, or ultraviolet (UV) radiation. The first thermal treatment process may be performed at a temperature in a range of 550° C. to 750° C. In some example embodiments, the first thermal treatment process may be performed at least one of using oxygen, nitrogen, or argon gas at a flow rate in a range of 100 sccm to 5000 sccm. In some example embodiments, the first thermal treatment process may be performed at a pressure in a range of 0.1 Torr to 10 Torr. In other example embodiments, the first thermal treatment process may be performed using the ultraviolet (UV) radiation at a pressure in a range of 0 Torr to 0.01 Torr. The first thermal treatment process may be performed for a time of 30 seconds to 200 seconds.

A hydroxyl group (OH—) included in the channel region may be removed by the first thermal treatment process. Thus, it is possible to reduce or prevent the initial oxide layer from being deteriorated by the hydroxyl group (OH—) during a subsequent process of forming the initial oxide layer. As a result, reliability of the semiconductor device may be improved.

The initial oxide layer may include a silicon oxide layer and may be formed by a thermal oxidation process.

The second thermal treatment process may be performed by substantially the same method as the first thermal treatment process. However, the inventive concepts are not limited thereto. A hydroxyl group (OH—) existing in the initial oxide layer may be removed by the second thermal treatment process, thereby reducing or preventing deterioration of the initial oxide layer and/or improving the reliability of the semiconductor device.

The high-k dielectric layer may include at least one of hafnium oxide, hafnium-silicon oxide, lanthanum oxide, zirconium oxide, zirconium-silicon oxide, tantalum oxide, titanium oxide, barium-strontium-titanium oxide, barium-titanium oxide, strontium-titanium oxide, lithium oxide, aluminum oxide, lead-scandium-tantalum oxide, or lead-zinc niobate.

Referring to FIG. 2, a method of manufacturing a semiconductor device according to other example embodiments may include loading a substrate including a channel region of a transistor into a process chamber (S210), performing a first thermal treatment process on the substrate (S220), forming an initial oxide layer on the substrate (S230), performing a second thermal treatment process on the substrate including the initial oxide layer (S240), and/or forming a high-k dielectric layer on the initial oxide layer (S250).

In some example embodiments, one of the first thermal treatment process and the second thermal treatment process may be omitted.

The substrate may be a silicon substrate such as a bulk silicon substrate or a silicon-on-insulator (SOI) substrate, and the channel region of the transistor may include germanium (Ge). For example, the channel region of the transistor may be formed of silicon-germanium (SiGe).

The process chamber may include a single-wafer type chamber or a batch type chamber.

The first thermal treatment process may be performed on the substrate using at least one of oxygen, nitrogen, argon, or ultraviolet (UV) radiation. The first thermal treatment process may be performed at a temperature ranging from 550° C. to 750° C. In some example embodiments, the first thermal treatment process may be performed at least one of using oxygen, nitrogen, or argon gas at a flow rate in a range of 100 sccm to 5000 sccm. In some example embodiments, the first thermal treatment process may be performed at a pressure in a range of 0.1 Torr to 10 Torr. In other example embodiments, the first thermal treatment process may be performed using the ultraviolet (UV) radiation at a pressure in a range of 0 Torr to 0.01 Torr. The first thermal treatment process may be performed for a time in a range of 30 seconds to 200 seconds.

A hydroxyl group (OH—) included in the channel region may be removed by the first thermal treatment process. Thus, it is possible to reduce or prevent the initial oxide layer from being deteriorated by the hydroxyl group (OH—) during a subsequent process of forming the initial oxide layer. As a result, reliability of the semiconductor device may be improved.

The initial oxide layer may include a silicon oxide layer and may be formed by a thermal oxidation process.

The second thermal treatment process may be performed by substantially the same method as the first thermal treatment process. However, the inventive concepts are not limited thereto. A hydroxyl group (OH—) existing in the initial oxide layer may be removed by the second thermal treatment process, thereby reducing or preventing deterioration of the initial oxide layer and/or improving the reliability of the semiconductor device. In some example embodiments, at least one of the first thermal treatment process and the second thermal treatment process may be performed in-situ in the process chamber in which the initial oxide layer is formed.

The high-k dielectric layer may include at least one of hafnium oxide, hafnium-silicon oxide, lanthanum oxide, zirconium oxide, zirconium-silicon oxide, tantalum oxide, titanium oxide, barium-strontium-titanium oxide, barium-titanium oxide, strontium-titanium oxide, lithium oxide, aluminum oxide, lead-scandium-tantalum oxide, or lead-zinc niobate.

A semiconductor device according to some example embodiments of the inventive concepts will be described with reference to FIGS. 3, 4A and 4B.

FIG. 3 is a plan view illustrating a semiconductor device according to some example embodiments of the inventive concepts.

Referring to FIG. 3, a semiconductor device may include a substrate 100 on which a channel region 110 of a transistor is formed. A gate electrode 140 may be formed to intersect the channel region 110.

The substrate 100 may be a silicon substrate such as a bulk silicon substrate or a silicon-on-insulator (SOI) substrate, and the channel region 110 of the transistor may include germanium (Ge). For example, the channel region 110 of the transistor may be formed of silicon-germanium (SiGe).

The gate electrode 140 may include a metal layer including at least one of titanium (Ti), titanium nitride (TiN), tantalum (Ta), tantalum nitride (TaN), tungsten (W), copper (Cu), aluminum (Al), or any mixture thereof.

A source/drain region may be formed in the channel region 110 not overlapping with the gate electrode 140 by a subsequent process.

FIG. 4A is a cross-sectional view taken along a line A-A of FIG. 3, and FIG. 4B is a cross-sectional view taken along a line B-B of FIG. 3.

Referring to FIGS. 4A and 4B, the channel region **110** of the transistor may be formed to protrude from the substrate **100**. In some example embodiments, after a channel layer may be formed on the substrate **100** by a silicon epitaxial growth method, a patterning process that includes a photolithography process and an etching process may be performed on the channel layer to form the channel region **110**. The channel region **110** may include germanium (Ge). For example, the channel region **110** may be formed of silicon-germanium (SiGe).

A device isolation layer **112** may be formed on the substrate **100**. The device isolation layer **112** may be formed to cover a portion of a sidewall of the channel region **110**. The device isolation layer **112** may include a silicon oxide layer.

An initial oxide layer **120** may be formed on the protruding channel region **110**. The initial oxide layer **120** may include a silicon oxide layer and be formed by a thermal oxidation process.

A high-k dielectric layer **130** may be formed on the initial oxide layer **120**. The high-k dielectric layer **130** may include at least one of hafnium oxide, hafnium-silicon oxide, lanthanum oxide, zirconium oxide, zirconium-silicon oxide, tantalum oxide, titanium oxide, barium-strontium-titanium oxide, barium-titanium oxide, strontium-titanium oxide, lithium oxide, aluminum oxide, lead-scandium-tantalum oxide, or lead-zinc niobate.

The gate electrode **140** may be formed on the high-k dielectric layer **130**. The gate electrode **140** may include a metal layer including at least one of titanium (Ti), titanium nitride (TiN), tantalum (Ta), tantalum nitride (Ta₂N₃), tungsten (W), copper (Cu), aluminum (Al), or any mixture thereof.

A method of fabricating a semiconductor device according to some example embodiments of the inventive concepts will be described with reference to FIGS. 5A to 5F. FIGS. 5A to 5F are perspective views illustrating a method of manufacturing a semiconductor device according to some example embodiments of the inventive concepts.

Referring to FIG. 5A, a channel region **110** is formed on a substrate **100**. The substrate **100** may be a silicon substrate such as a bulk silicon substrate or a silicon-on-insulator (SOI) substrate.

The channel region **110** may be formed to protrude from the substrate **100**. In some example embodiments, after a mask pattern may be formed on the substrate **100**, the substrate **100** may be etched by a predetermined or desired depth using the mask pattern as an etch mask to form the channel region **110**. In other example embodiments, a channel layer may be formed on the substrate **100** by a silicon epitaxial growth method, and a patterning process including a photolithography process and an etching process may be then performed on the channel layer to form the channel region **110**. The channel region **110** may include germanium (Ge). For example, the channel region **110** may be formed of silicon-germanium (SiGe).

A device isolation layer **112** may be formed on the substrate **100**. The device isolation layer **112** may include a silicon oxide layer that is formed by a high-density plasma (HDP) deposition method or a flowable chemical vapor deposition (FCVD) method. In some example embodiments, a silicon oxide layer may be formed on the substrate **100** to sufficiently cover the channel region **110**, and a planarization process and an etch-back process may be performed on the silicon oxide layer to expose a top surface and a sidewall of the channel region **110** and to form the device isolation layer **112**. A height of the exposed sidewall of the channel region **110** may be in a range of, but not limited to, 200 Å to 500 Å.

Referring to FIG. 5B, a first thermal treatment process **115** may be performed on the exposed channel region **110**. The first thermal treatment process **115** may be performed using at least one of oxygen, nitrogen, argon, or ultraviolet (UV) radiation at a temperature in a range of 550° C. to 750° C. In some example embodiments, the first thermal treatment process **115** may be performed at least one of using oxygen, nitrogen, or argon gas at a flow rate in a range of 100 sccm to 5000 sccm. In some example embodiments, the first thermal treatment process **115** may be performed at a pressure in a range of 0.1 Torr to 10 Torr. Alternatively, the first thermal treatment process **115** may be performed using the ultraviolet (UV) radiation at a pressure in a range of 0 Torr to 0.01 Torr. The first thermal treatment process **115** may be performed for a time of 30 seconds to 200 seconds.

A hydroxyl group (OH—) included in the channel region **110** may be removed by the first thermal treatment process **115**. Thus, it is possible to reduce or prevent an initial oxide layer from being deteriorated by the hydroxyl group (OH—) during a subsequent process of forming the initial oxide layer. As a result, it is possible to improve reliability of the semiconductor device.

Referring to FIG. 5C, an initial oxide layer **120** may be formed on the channel region **110**. The initial oxide layer **120** may include a silicon oxide layer formed by a thermal oxidation process or a chemical vapor deposition (CVD) process.

Referring to FIG. 5D, a second thermal treatment **125** may be performed on the initial oxide layer **120**. The second thermal treatment **125** may be performed by substantially the same method as the first thermal treatment process **115**. However, the inventive concepts are not limited thereto. A hydroxyl group (OH—) existing in the initial oxide layer **120** may be removed by the second thermal treatment process **125**, thereby reducing or preventing deterioration of the initial oxide layer **120** and/or improving the reliability of the semiconductor device.

Referring to FIG. 5E, a high-k dielectric layer **130** may be formed on the initial oxide layer **120**. The high-k dielectric layer **130** may be formed by an atomic layer deposition (ALD) process or a chemical vapor deposition (CVD) process. The high-k dielectric layer **130** may include at least one of hafnium oxide, hafnium-silicon oxide, lanthanum oxide, zirconium oxide, zirconium-silicon oxide, tantalum oxide, titanium oxide, barium-strontium-titanium oxide, barium-titanium oxide, strontium-titanium oxide, lithium oxide, aluminum oxide, lead-scandium-tantalum oxide, or lead-zinc niobate.

Referring to FIG. 5F, a gate electrode **140** may be formed on the high-k dielectric layer **130**. The gate electrode **140** may include a metal layer including at least one of titanium (Ti), titanium nitride (TiN), tantalum (Ta), tantalum nitride (Ta₂N₃), tungsten (W), copper (Cu), aluminum (Al), or any mixture thereof.

After the processes described above are performed, processes of forming an interlayer insulating layer, an interconnection, and/or a wire may be further performed to manufacture the semiconductor device according to some example embodiments of the inventive concepts.

A method of manufacturing a semiconductor device according to other example embodiments of the inventive concepts will be described with reference to FIGS. 6A to 6K. FIGS. 6A to 6K are perspective views illustrating a method of manufacturing a semiconductor device according to other example embodiments of the inventive concepts.

Referring to FIG. 6A, a plurality of channel regions **210** may be formed on a substrate **200**. The substrate **200** may be a silicon substrate such as a bulk silicon substrate or a silicon-on-insulator (SOI) substrate.

Each of the channel regions **210** may be formed to have a shape protruded from the substrate **200**. In some example embodiments, after a mask pattern may be formed on the substrate **200**, the substrate **200** may be etched by a predetermined or desired depth using the mask pattern as an etch mask to form the channel regions **210**. In other example embodiments, a channel layer may be formed on the substrate **200** by a silicon epitaxial growth method, and a patterning process that includes a photolithography process and an etching process may be then performed on the channel layer to form the channel regions **210**. The channel regions **210** may include germanium (Ge). For example, the channel regions **210** may be formed of silicon-germanium (SiGe).

A device isolation layer **220** may be formed on the substrate **200**. The device isolation layer **220** may include a silicon oxide layer that is formed by a high-density plasma (HDP) deposition method or a flowable chemical vapor deposition (FCVD) method. In some example embodiments, a silicon oxide layer may be formed on the substrate **200** to sufficiently cover the channel regions **210**, and a planarization process and an etch-back process may be performed on the silicon oxide layer to expose a top surface and a sidewall of the channel regions **210** and to form the device isolation layer **220**. A height of the exposed sidewall of the channel region **210** may be in a range of 200 Å to 500 Å. However, the inventive concepts are not limited thereto.

Referring to FIG. 6B, a dummy gate pattern **240** may be formed to cross over the channel regions **210**. The dummy gate pattern **240** may include poly-crystalline silicon. A sacrificial insulating layer **230** may be formed under the dummy gate pattern **240**, and a hard mask pattern **250** may be formed on the dummy gate pattern **240**.

In some example embodiments, a sacrificial insulating layer **230** and a poly-crystalline silicon layer may be formed on the channel regions **210**, and a chemical mechanical polishing (CMP) process or an etch-back process may be performed to planarize a top surface of the poly-crystalline silicon layer. The hard mask pattern **250** may be formed on the planarized top surface of the poly-crystalline silicon layer, and the poly-crystalline silicon layer may be then patterned using the hard mask pattern **250** as an etch mask to form the dummy gate pattern **240**.

Referring to FIG. 6C, a spacer **260** may be formed on a sidewall of the dummy gate pattern **240** and sidewalls of the channel regions **210**. The spacer **260** may include at least one of silicon nitride (SiN) and silicon oxynitride (SiON). In some example embodiments, a silicon nitride layer and/or a silicon oxynitride layer may be formed on the hard mask pattern **250** and the channel regions **210**, and then, an etch-back process may be performed on the silicon nitride layer and/or the silicon oxynitride layer to expose the device isolation layer **220** formed on the substrate **200**. Thus, the spacer **260** may be formed. A top surface of the hard mask pattern **250** and top surfaces of the channel regions **210** may be exposed together.

Referring to FIG. 6D, the top surfaces of the channel regions **210** may be etched by a predetermined or desired depth to form a plurality of first recess regions **270**. The etched surfaces of the channel regions **210** (e.g., bottom surfaces of the first recess regions **270**) may be a little higher than a top surface of the device isolation layer **220**. However, the inventive concepts are not limited thereto.

Referring to FIG. 6E, an epitaxial layer **280** may be formed in each of the first recess regions **270** of FIG. 6D. A top surface of the epitaxial layer **280** may be formed to protrude from the first recess regions **270**. The top surface of the epitaxial layer **280** may be lower than the top surface of the hard mask pattern **250**.

The epitaxial layer **280** may be a source/drain region of an N-type metal-oxide-semiconductor (NMOS) or P-type metal-oxide-semiconductor (PMOS) transistor, and N-type or P-type dopants may be doped in-situ during the formation of the epitaxial layer **280**.

Referring to FIG. 6F, an interlayer insulating layer **290** may be formed to cover the epitaxial layer **280**, the device isolation layer, and the spacer **260**. The interlayer insulating layer **290** may include a silicon oxide layer that is formed by a high-density plasma (HDP) deposition method, a spin-on-glass (SOG) method, a chemical vapor deposition (CVD) method, or a flowable chemical vapor deposition (FCVD) method.

In some example embodiments, a silicon oxide layer may be formed on the hard mask pattern **250** and the spacer **260**, and a planarization process (e.g., an etch-back process or a chemical mechanical polishing (CMP) process) may be performed on the silicon oxide layer until the hard mask pattern **250** is exposed, thereby forming the interlayer insulating layer **290**.

Referring to FIG. 6G, the hard mask pattern **250**, the dummy gate pattern **240**, and the sacrificial insulating layer **230** may be removed to form a second recess region **300**. Portions of the channel regions **210** and a portion of the device isolation layer **220** may be exposed at a bottom of the second recess region **300**.

Referring to FIG. 6H, a first thermal treatment process **305** may be performed on the exposed channel regions **210**. The first thermal treatment process **305** may be performed using at least one of oxygen, nitrogen, argon, or ultraviolet (UV) radiation. The first thermal treatment process **305** may be performed at a temperature in a range of 550° C. to 750° C. In some example embodiments, the first thermal treatment process **305** may be performed at least one of using oxygen, nitrogen, or argon gas at a flow rate ranging from 100 sccm to 5000 sccm and at a pressure ranging from 0.1 Torr to 10 Torr. Alternatively, the first thermal treatment process **305** may be performed using the ultraviolet (UV) radiation at a pressure ranging from 0 Torr to 0.01 Torr. The first thermal treatment process **305** may be performed for a time in a range of 30 seconds to 200 seconds.

A hydroxyl group (OH—) included in the channel regions **210** may be removed by the first thermal treatment process **305**. Thus, it is possible to reduce or prevent an initial oxide layer from being deteriorated by the hydroxyl group (OH—) during a subsequent process of forming the initial oxide layer. As a result, reliability of the semiconductor device may be improved.

Referring to FIG. 6I, an initial oxide layer **310** may be formed on the channel regions **110** in the second recess region **300**. The initial oxide layer **310** may include a silicon oxide layer formed by a thermal oxidation process.

Referring to FIG. 6J, a second thermal treatment process **315** may be performed on the initial oxide layer **310**. The second thermal treatment process **315** may be performed by substantially the same method as the first thermal treatment process **305**. However, the inventive concepts are not limited thereto. A hydroxyl group (OH—) existing in the initial oxide layer **310** may be removed by the second thermal treatment process **315**, thereby reducing or preventing deterioration of the initial oxide layer **310** and/or improving the reliability of the semiconductor device.

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Referring to FIG. 6K, a high-k dielectric layer **320** may be formed on the initial oxide layer **310**. The high-k dielectric layer **320** may be formed by an atomic layer deposition (ALD) process or a chemical vapor deposition (CVD) process. The high-k dielectric layer **320** may include at least one of hafnium oxide, hafnium-silicon oxide, lanthanum oxide, zirconium oxide, zirconium-silicon oxide, tantalum oxide, titanium oxide, barium-strontium-titanium oxide, barium-titanium oxide, strontium-titanium oxide, lithium oxide, aluminum oxide, lead-scandium-tantalum oxide, or lead-zinc niobate.

A gate electrode **330** may be formed on the high-k dielectric layer **320**. The gate electrode **330** may include a metal layer including at least one of titanium (Ti), titanium nitride (TiN), tantalum (Ta), tantalum nitride (TaN), tungsten (W), copper (Cu), aluminum (Al), or any mixture thereof.

After the aforementioned processes are performed, processes of forming an interlayer insulating layer, an interconnection, and/or a wire may be further performed to manufacture the semiconductor device according to other example embodiments of the inventive concepts.

FIG. 7 is a schematic block diagram illustrating a system including a semiconductor device according to some example embodiments of the inventive concepts.

Referring to FIG. 7, a system **1000** includes a controller **1010**, an input/output (I/O) unit **1020**, a memory device **1030**, and an interface unit **1040**. The system **1000** may be a mobile system or a system transmitting or receiving data. In some example embodiments, the mobile system may be a personal digital assistant (PDA), a portable computer, a web tablet, a wireless phone, a mobile phone, a digital music player, or a memory card. The controller **1010** may control executing programs in the system **1000**. For example, the controller **1010** may include at least one of a microprocessor, a digital signal processor, a microcontroller, or other logic devices. The other logic devices may have a similar function to any one of the microprocessor, the digital signal processor, and the microcontroller. The I/O unit **1020** may be used to input data into or output data from the system **1000**. In other words, the system **1000** may be connected to an external system (e.g., a personal computer or a network) through the I/O unit **1020** so as to exchange data with the external system. The I/O unit **1020** may include at least one of, for example, a keypad, a keyboard, or a display device.

The memory device **1030** may store data and/or codes for operating the controller **1010** and/or may store data processed by the controller **1010**. The controller **1010** and/or the memory device **1030** may include the semiconductor device having the NMOS or PMOS transistor according to some example embodiments of the inventive concepts. For example, the controller **1010** and/or the memory device **1030** may include at least one of the semiconductor devices described with reference to FIGS. 1 to 6K.

The interface unit **1040** may correspond to a data transfer path between the system **1000** and an external system. The controller **1010**, the I/O unit **1020**, the memory device **1030**, and the interface unit **1040** may communicate with each other through a data bus **1050**. The system **1000** may be applied to a mobile phone, a MP3 player, a navigation system, a portable multimedia player (PMP), a solid state disk (SSD), or household appliances.

FIG. 8 is a schematic block diagram illustrating a memory card including a semiconductor device according to some example embodiments of the inventive concepts.

Referring to FIG. 8, a memory card **1100** may include a memory device **1110** and a memory controller **1120**. The

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memory device **1110** may store data and may include at least one of the semiconductor devices described with reference to FIGS. 1 to 6K.

The memory controller **1120** may read data stored in the memory device **1110** or may store data into the memory device **1110** in response to read/write request of a host **1130**. The memory controller **1120** may include at least one of the semiconductor devices described with reference to FIGS. 1 to 6K.

According to the aforementioned example embodiments of the inventive concepts, the thermal treatment process may be performed at least once before and/or after the gate dielectric layer is formed on the channel region of the transistor, thereby improving the reliability of the semiconductor device.

While the inventive concepts have been described with reference to example embodiments, it will be apparent to those skilled in the art that various changes and modifications may be made without departing from the spirits and scopes of the inventive concepts. Therefore, it should be understood that the above example embodiments are not limiting, but illustrative. Thus, the scopes of the inventive concepts are to be determined by the broadest permissible interpretation of the following claims and their equivalents, and shall not be restricted or limited by the foregoing description.

What is claimed is:

1. A method of manufacturing a semiconductor device, the method comprising:

providing a substrate having a channel region of a transistor, the channel region protruding upwardly from the substrate and including silicon-germanium (SiGe);
forming an initial oxide layer on the protruding channel region;
performing a thermal treatment process at least once before forming the initial oxide layer so as to remove a hydroxyl group (OH—) in the channel region; and
forming a high-k dielectric layer on the initial oxide layer, wherein the thermal treatment process is performed using the ultraviolet (UV) radiation at a pressure in a range of 0 Torr to 0.01 Torr.

2. The method of claim 1, wherein the thermal treatment process is performed in-situ using at least one of oxygen, nitrogen, argon, or ultraviolet (UV) radiation in a process chamber in which the initial oxide layer is formed.

3. The method of claim 2, wherein the thermal treatment process is performed at a temperature in a range of 550° C. to 750° C.

4. The method of claim 3, wherein the thermal treatment process is performed using at least one of oxygen, nitrogen, or argon gas at a flow rate in a range of 100 sccm to 5000 sccm.

5. The method of claim 3, wherein the thermal treatment process is performed for a time in a range of 30 seconds to 200 seconds.

6. A method of manufacturing a semiconductor device, the method comprising:

providing a substrate having a channel region protruding upwardly from the substrate and including silicon-germanium (SiGe);
forming an initial oxide layer on the substrate; and
performing a first thermal treatment process on the protruding channel region which is exposed using at least one of oxygen, nitrogen, argon, or ultraviolet (UV) radiation in-situ before forming the initial oxide layer so as to remove a hydroxyl group (OH—) in the protruding channel region,

wherein the first thermal treatment process is performed using the ultraviolet (UV) radiation at a pressure in a range of 0 Torr to 0.01 Torr.

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7. The method of claim 6, further comprising:
performing a second thermal treatment process using at
least one of oxygen, nitrogen, argon, or ultraviolet (UV)
radiation in-situ after forming the initial oxide layer so
as to remove a hydroxyl group (OH—) in the initial
oxide layer, 5

wherein the initial oxide layer includes silicon oxide
(SiO₂).

8. The method of claim 7, wherein the second thermal
treatment process is performed by substantially the same 10
method as the first thermal treatment process.

9. The method of claim 8, wherein each of the first and
second thermal treatment processes is performed at a tem-
perature in a range of 550° C. to 750° C.

10. The method of claim 9, wherein each of the first and 15
second thermal treatment processes is performed using at
least one of oxygen, nitrogen, or argon gas at a flow rate in a
range of 100 sccm to 5000 sccm.

11. The method of claim 9, further comprising forming a
high-k dielectric layer on the initial oxide layer. 20

12. A method of manufacturing a semiconductor device,
the method comprising:

loading a substrate having a channel region of a transistor
into a process chamber, the channel region protruding
upwardly from the substrate and including silicon-ger-
manium (SiGe);

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performing a first thermal treatment process using at least
one of oxygen, nitrogen, argon, or ultraviolet (UV)
radiation on the protruding channel region which is
exposed so as to remove a hydroxyl group (OH—) in the
protruding channel region;

forming an initial oxide layer on the protruding channel
region treated by the first thermal treatment process in
the process chamber in-situ, the initial oxide layer
including silicon oxide (SiO₂); and

performing a second thermal treatment process using at
least one of oxygen, nitrogen, argon, or ultraviolet (UV)
radiation on the initial oxide layer so as to remove a
hydroxyl group (OH—) in the initial oxide layer,

wherein the first thermal treatment process is performed
using the ultraviolet (UV) radiation at a pressure in a
range of 0 Torr to 0.01 Torr.

13. The method of claim 12, wherein the second thermal
treatment process is performed in-situ in the process chamber.

14. The method of claim 12, wherein each of the first and
second thermal treatment processes is performed at a tem-
perature in a range of 550° C. to 750° C.

15. The method of claim 12, further comprising forming a
high-k dielectric layer on the initial oxide layer after perform-
ing the second thermal treatment process.

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